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Water Treatment Process Monitoring and Evaluation

Richard P. Beverly, PE



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AWWA Publications Manager: Gay Porter De Nileon
Technical Editor/Project Manager: Melissa Valentine
Cover Design: Cheryl Armstrong
Production: Sheryl Tongue

Library of Congress Cataloging-in-Publication Data

Water treatment process monitoring and evaluation / by Richard P. Beverly
p. cm.
Includes bibliographic references.
ISBN 978-1-58321-858-7
1. Water treatment plants--Evaluation. 2. Plant performance--Evaluation. 3. Water--Purification--Evaluation. I. Beverly, Richard P.
TD434.W425 2011
628.1′62--dc23
2011034828

ISBN 1-58321-858-0
978-158321-858-7

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CHAPTER ONE

Introduction

The intent of this handbook is to provide information and tools to assist water treatment plant operators in monitoring plant operations and evaluating plant operational changes (such as the changes in treatment efficiency due to changes in the raw water) in order to help the operators make corresponding process changes (water chemistry, etc.) to keep their plants operating properly.

To accomplish this goal, a "building block" approach is used: First the handbook methodically builds up background information that all operators should know to effectively troubleshoot treatment problems—detailing, for example, such treatment plant fundamentals as basic design principles and design issues, process flow diagrams, data monitoring and record keeping, and instrumentation and control systems (including response time). Then the handbook delves into the main topic of the evaluation of monitoring data in detail—covering, for example, turbidity, filter-to-waste cycle, filter run time, head loss, alkalinity, pH, filtration efficiency, and the like. Case histories, plentiful graphic illustrations, and a rich assortment of appendix material augment the text.

TREATMENT PLANT DEFINITION

For the purposes of this discussion, the term *treatment plant* will refer primarily to water treatment, although wastewater filtration is also related. A conventional treatment plant is assumed for discussion purposes, although any type may be substituted, including package plants, either gravity or pressure treatment units, as well as microfiltration or reverse osmosis. All the guidelines included herein can be applied to all of these types of treatment plants, including conventional treatment used for pretreatment for membrane filtration.

OPERATIONAL NEEDS

Field experience has demonstrated that resolving operational issues may not be easy in some cases. Besides training in treatment processes, operators need a knowledge of basic chemistry, experience in their own treatment plant, and the ability to analyze process changes and make

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the necessary changes to maintain the desired water quality. To accurately perform these tasks, the treatment plant should be provided with maximum operational flexibility and adequate instrumentation to identify the reason for any process changes that may occur.

PROPER OPERATION

The ability to provide proper operation starts at the design level. The plant designer should have a good grasp of the raw water chemistry at the particular site, as well as the treatment processes needed to achieve the desired water quality, and finally a very good grasp of the workings of all the plant equipment. These are considerable requirements. Many engineers design water treatment plants, but the ability to include operational flexibility and monitoring to make a plant "livable and workable" is another matter.

In other words, if the plant is not designed properly, it may be difficult to operate regardless of its size. One of the many admirable qualities of many operators is that they seem to find a way to make things work in spite of the way the plant is laid out and built. Still, the designers can go a long way toward making a plant more livable and easier to operate.

DESIGN KNOWLEDGE

An operator does not need have design capability or training. However, an operator would have a great advantage in having some knowledge of process design, including such things as the desired instrumentation, the desired location of such instrumentation, the proper construction of sampling points, the necessary detention time required after chemical addition, as well as other issues such as the effect on the plant from taking one or more filters off-line for backwashing. Both operators and system managers would also benefit by knowing if their plant is lacking in the necessary analytical tools so that they can take steps to obtain them.

OPERATOR NEEDS

It is often said that experience is the best teacher. However, obtaining the required experience can be difficult, unless the necessary tools are available. An example is when a new plant has been built that uses technology or equipment different from that which an experienced operator is used to. Another example is where an inexperienced

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operator comes to a new plant. In such cases, a detailed operational manual would be extremely beneficial but is often unavailable.

CONTENT AND GOALS OF THIS HANDBOOK

This handbook aims to cover water treatment plant fundamentals that are essential for all operators who want to identify process problems, evaluate the cause(s), and develop effective solutions. Preliminary chapters present information about design that all operators should know including the development of process flow diagrams (a hypothetical plant is used as an example). Next, various aspects of monitoring data, such as control systems, instrumentation, and record keeping, are discussed with a special chapter devoted to response time. Finally, the handbook presents a detailed discussion of the evaluation of process data over time—covering a wide range of water treatment plant process issues.

The intent of this handbook is to provide operators and system managers with the analysis tools to understand and operate a plant and to be able to identify and correct any plant deficiencies.

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CHAPTER TWO

Preliminary Design

When a treatment plant is planned, some elements—for example, a preliminary design report and a pilot study—will aid those operating and troubleshooting the full-scale plant in the future. This chapter and several following chapters will describe such elements.

The first phase of a treatment plant design is to prepare a preliminary design report. The preliminary design report establishes the scope of the treatment processes to be used; determines the estimated cost of construction; determines the chemical feed requirements; and determines the methods to be used for disposal of chemical waste, as well as other issues.

In some cases, the disposal of the chemical waste from the plant governs the type of treatment processes to be used. For example, one such case involved the treatment and removal of iron and arsenic from drinking water in a remote location. On-site disposal of wastewater was also required because of the remote location. At that location, chemicals that ordinarily would have been used were prohibited by the site constraints. An alternate treatment technology was therefore required.

PILOT STUDIES

A pilot study is often included as part of the preliminary design report. When an entirely new treatment plant is to be constructed, the regulatory authorities often require that a pilot study be performed to confirm that the preliminary design is valid and will work. The project owner and/or the entity providing the project financing may also require a pilot study.

A pilot study is extremely valuable and should be conducted. A pilot study report provides the basis for design in addition to being a valuable training tool for the operators. It is also a valuable resource for future plant operations.

PLANT EXPANSION

If an expansion of an existing plant is planned, a pilot study may not be required if the same treatment processes and equipment are to be

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used. However, if different treatment processes are planned, a pilot study may still be required. Some regulatory authorities require pilot studies if new treatment technologies are to be used.

PRELIMINARY DESIGN WITHOUT A PILOT STUDY

If a preliminary design report is completed without the benefit of a pilot study, the designer is assuming complete responsibility for the success of the proposed treatment processes. In such a case, a comprehensive operations manual should be prepared for the benefit of the plant operators. Such an operations manual should be provided in any case. Without a pilot study for reference, the importance of the operations manual increases. Chapter 13 will discuss operations manuals, and chapter 3 will review pilot studies.

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CHAPTER THREE

Pilot Study Purpose

Pilot studies provide plant operators and system managers with a valuable resource in determining how the plant should be operated. On many occasions, operators could have used a pilot study report for help in determining how to resolve treatment issues.

There are numerous benefits of conducting a pilot study including verification of the treatment process selection, verification that the treatment processes can provide the desired water quality, sizing the treatment plant processes including the unit flow rate for granular media filters or the flux rate for membrane filtration, determining the optimum chemical feed rates and sizing that equipment, as well as operator training.

PILOT FILTER STUDIES

Pilot filter studies consist of small-scale testing to determine the treatability of a water source, to determine the effectiveness of various media types, and/or to determine the chemical feed requirements. The intent is to duplicate the treatment processes to be used for the full-scale plant. Depending on the type of pilot equipment used, the flow rate for testing purposes is usually in the range of 1–50 gpm, although many pilot test flow rates are in the range of 1–5 gpm.

In most cases, a pilot study program consists of two stages; the first is bench-scale/jar testing to establish a chemical feed baseline for the second stage of continuous process testing.

PILOT STUDY GOALS

The pilot study goals must be clearly defined before beginning any actual test work. Typical goals are discussed in the following sections.

Treatability

The treatability of the source water should be determined in terms of processes needed and chemical requirements. In other words, there may be a number of different treatment processes that may work to some extent. However, the ones that are expected to be the most effective

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should be piloted. Then, the pilot study results should be evaluated for highest efficiency, in terms of cost, chemical use, and disposal, as well as the quantity of wastewater produced. There may be cases, as mentioned previously, where the method available for wastewater disposal may dictate the selection of the treatment process to be used.

Effectiveness

The effectiveness of various treatment processes should be verified including any potential new technologies. For example, if two different processes will work, does one produce any other benefits, other than the basic treatment requirements? If all other criteria are approximately the same, does one produce less wastewater or does one produce a higher quality water, over and above the basic requirements? In such cases, long term benefits may be such that cost may not be the best method of evaluation, unless the cost differences are great.

Chemical Feed

The chemicals to be used in treatment and the proper feed rates for each should be verified. This information is very necessary for sizing the chemical feed equipment for the full-scale plant. There may be cases where two different chemicals will work, but one may require the use of a higher feed rate. In such cases, required maintenance and the quantity of wastewater produced may be critical factors in selecting the chemicals to be used.

Early Warning

Some plants have raw water that is subject to rapid changes. In such cases, a permanent pilot unit may be desirable, if it can provide preliminary results faster than the water that passes through the full-scale plant. With such an early warning, water chemistry changes can be made rapidly before any poor quality water passes through the plant to the final instrumentation. If poor quality water is allowed to enter the plant without adequate process adjustments, it may result in production of poor quality water and a considerable loss of production time.

Operator Training

Pilot units provide a highly useful tool for operator training, either on a temporary basis during the pilot study or on a permanent basis as part of the full-scale plant equipment. An example is conducting chemical trials to determine if a different chemical can provide more efficient treatment than the chemical currently being used. Trials can

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be conducted without the risk of upsetting the full-scale plant if the trial chemical does not work as well.

Another potential benefit, especially for granular media filter types of pilot studies, is the ability to visually demonstrate media fluidization and classification during the backwash cycle.

PILOT TESTING PROTOCOL

Having a testing plan or protocol is critical to a successful pilot study. The pilot testing protocol must be completed before beginning any testing. It will provide an outline for the final pilot study report. One microfiltration pilot test failed due to a lack of proper direction. The pilot test operators only ran one chemical setting without including any changes. Once preliminary lab tests were run to establish the expected range of chemical settings, the pilot test was concluded successfully.

A basic outline of items in a typical pilot testing protocol, or operational plan, is included in the following section.

Protocol

A pilot testing protocol should include the following:

- **Raw Water Quality—**The raw water quality should be determined using test wells for groundwater or samples from a surface supply, depending on the source planned for the full-scale plant.
- **Treatment Processes—**Using the desired finished water quality, the treatment processes to be tested should be determined, such as conventional treatment with coagulation, greensand, or membranes, and so on. NOTE: The pilot testing may include multiple treatment options and equipment trains.
- **Flow/Flux Rates—**A range of unit flow or flux rates to be tested should be determined. Knowing the acceptable ranges for the flow/flux rates will be used in sizing the full-scale plant.
- **Chemicals—**The chemicals needed for such purposes as buffering, oxidation, coagulation, filter aid, posttreatment pH adjustment, disinfection, and so on should be determined.
- **Bench-Scale/Jar Tests—**Bench-scale/jar tests should be performed to establish ranges of chemicals for further testing. The lack of these preliminary tests may make pilot testing more difficult and time-consuming.
- **Pilot Testing—**Continuous process testing should be conducted with small-scale filters or membrane units, using the

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information collected from the previous sections. As noted, one or more treatment types may be tested simultaneously.

NOTES:

a. The protocol should include testing of a range of flow rates and chemical rates to ensure that the optimum operating conditions are found. However, the entire testing plan may not have to be completed if the bench-scale/jar testing provides an accurate starting point or if an acceptable solution is easily found. However, adequate testing should be completed to insure that the optimum conditions have been identified.

b. The duration of the testing will vary depending on the source water and the requirements of the regulatory agencies. For example, groundwater normally changes very little and a short testing period may be adequate. However, testing through several seasons may be required for surface water sources.

BENCH-SCALE/JAR TESTING

Bench-scale/jar testing should be performed to determine a starting point for the pilot testing program. Here again, the intent of this testing is to simulate the full-scale treatment processes. A brief outline for this procedure is given in the following sections. Appendix A has more complete information on the following steps.

1. Prepare stock solutions. Add various amounts of chemical to the jars. NOTE: Only one chemical at a time should be tested, until the optimum feed rate for it is established. Then, that amount can be added to all the jars, and the next chemical can be added in varying amounts.
2. Simulate a flash mixing step by stirring the jars rapidly for 30–60 seconds.
3. Determine the contact time necessary for the desired chemical reactions (oxidation or coagulation).
4. Simulate clarification (if required) by turning off the mixer and letting the jars settle for 2–3 minutes.
5. Simulate filtration by decanting the jars and running the supernatant through a vacuum filter. A vacuum filter is a necessary device for testing high quality raw water and for determining if the finished water quality goals can be achieved.

NOTES:

a. The optimum pH range for some coagulants such as alum is critical. For those cases, a buffering chemical may be necessary to arrive at the optimum point.

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b. Records should be kept for all tests, which will provide an operational history for the plant. Historical records will be discussed in more detail in chapter 11 of this handbook.
c. Refer to Reference 1 for an extended discussion of bench-scale/jar testing. Refer also to appendix A for sample jar testing forms and procedures.
d. Verify these results for compliance with removal/treatment goals. Depending on the type of contamination being treated, the removal indicators may be different. Although not a complete list, several contaminants are discussed in the following section.
e. Typical contaminants:
   - **Iron and Manganese—**Lab test kits should be available on site for these contaminants. A spectrophotometer is recommended for more accurate results, not a simple colorimeter.
   - **Arsenic—**Accurate results for arsenic removal may require formal lab testing, which takes time. However, during bench-scale/jar testing or pilot testing, more rapid results are required. Iron frequently occurs with arsenic in groundwater or may be added to assist in the removal of arsenic. In either case, testing for iron removal may be used as an indicator for arsenic and is often acceptable for preliminary pilot test results.
   - **Turbidity—**Residual turbidity is easily measured by a spectrophotometer or bench-scale turbidimeter. However, the samples should have first been run through a vacuum filter as previously discussed.
   - **Color/Organics—**Dissolved color will normally pass through a filter, perhaps even a microfiltration unit. Properly coagulated color can then be removed by filtration. Removal efficiency can be verified by a spectrophotometer or turbidimeter, after chemical coagulation and vacuum filtration.

BENCH-SCALE/JAR TESTING SUMMARY

Sample jar testing forms and procedures are included in appendix A.

The bench-scale/jar testing procedure should not be performed until adequate lab instrumentation is available to evaluate the results, as previously noted. As a general rule, if jar testing is successful, the pilot filter study will be also.

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There is no point in starting a pilot filter study until the bench-scale tests are successful and a testing plan (protocol) has been developed. Starting without either can significantly extend the testing period and waste time and money.

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CHAPTER FOUR

Pilot Filter Composition

PILOT FILTER TYPES

The design of pilot filters often varies, depending on the contaminant to be removed and the desired finished water quality. Pilot filters can be of a variety of types, including the following:

Conventional

Figure 4-1 is an example of a completely assembled conventional pilot filter for granular media, including all the components described in the following sections, with all equipment mounted on a back panel, which has wheels for ease of movement.

Conventional media types may include multi-media (anthracite, silica sand, and garnet sand), dual media (anthracite and silica sand), or mono-media (coarse sand, gravel, or anthracite).

Figure 4-2 is a flow diagram illustrating the components used for the pilot filter column in Figure 4-1.

Conventional Pilot Filter Composition

Although some pilot filters operate by gravity, pressure filters are more common and compact, even if the full-scale plant will operate by gravity. For conventional filtration, a minimum 5-ft-tall clear column is recommended with a 6-in. inside diameter. Larger diameter pilot filters are recommended if available, because the wall surface (side wall) effect is less. Refer to Reference 1 for a discussion of *side wall effect*.

NOTE: The walls of a pilot filter are typically glass or plastic, and as such are "slicker" than full-scale filter walls and tend to have a greater tendency for short circuiting down the walls, thereby bypassing the media and resulting in poorer filtration efficiency. Therefore, the bigger diameter the pilot filter, the better the results may be. Full-scale granular media filters are often more efficient than pilot units for this reason.

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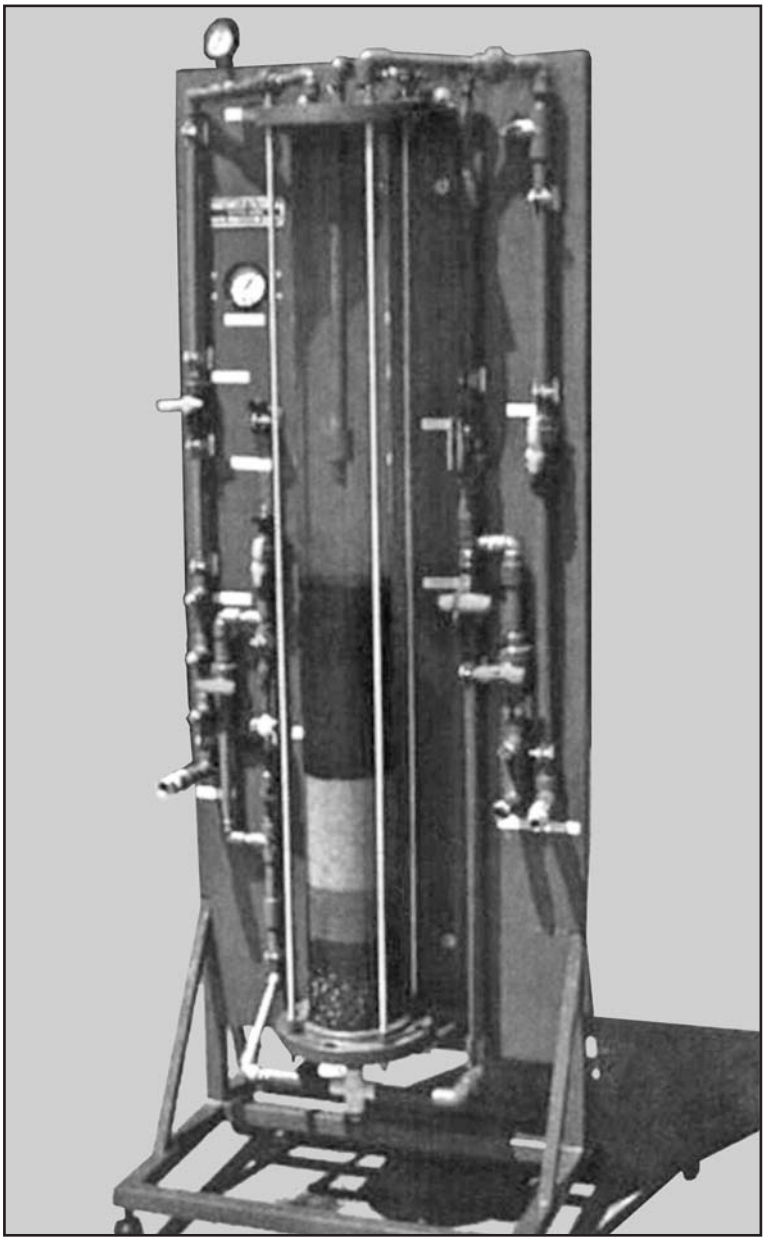


Figure 4-1 Typical pilot filter

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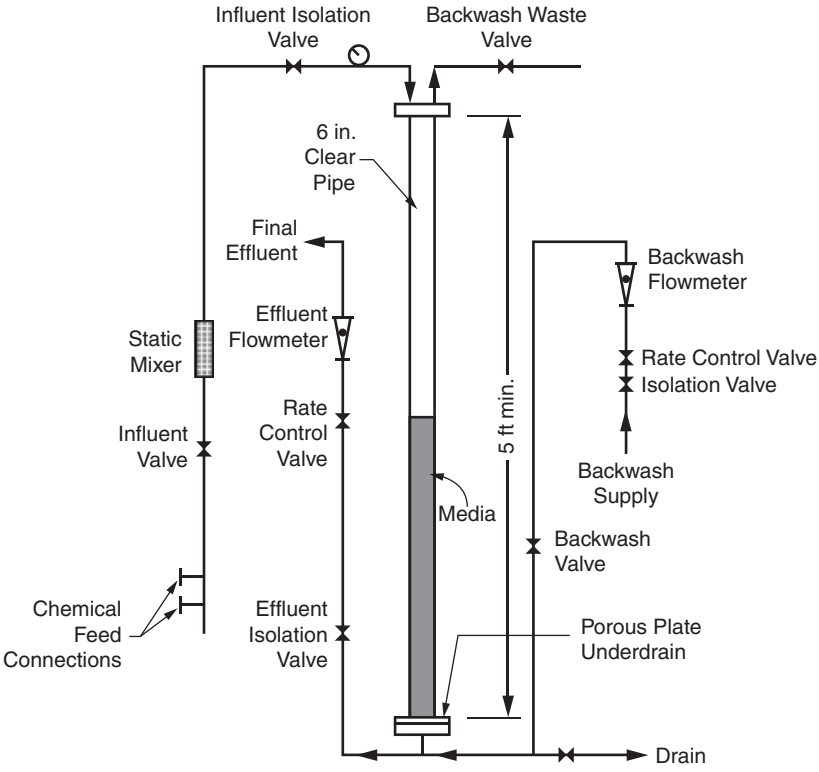


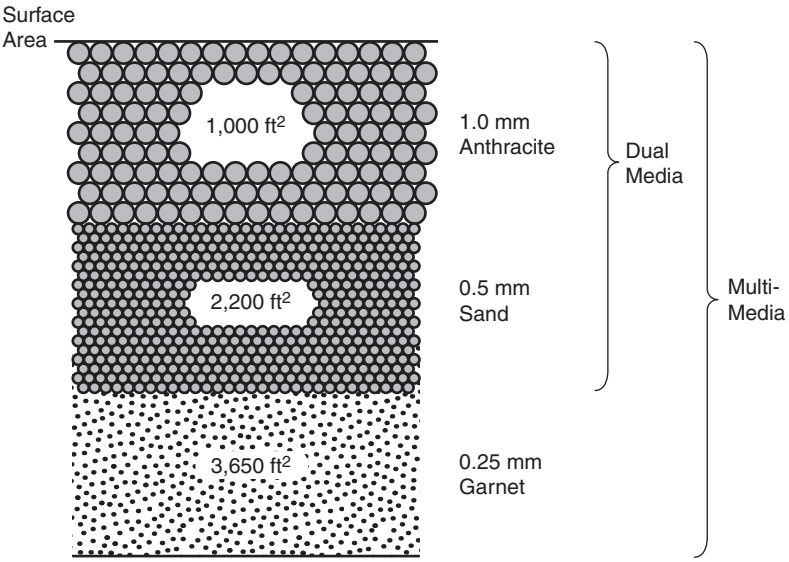
Figure 4-2 Conventional pilot filter flow diagram

Porous Plate Underdrain

As used in municipal type filters, a porous plate is a substitute for support gravel over some underdrain types. It consists of plastic beads heat welded together, with the intent of retaining filter sand without the use of the support gravel. Porous plates are used to cover the normal underdrain and to eliminate the height in the filter normally required for support gravel. The main underdrain should provide the water distribution capability, not the porous plate. A porous plate may actually be used as the underdrain in the pilot filter to eliminate the height required for support gravel, even if gravel is to be used in the full-scale plant. The small size of most pilot filters would also allow the porous plate to be used for distribution purposes.

A porous plate in the pilot filter also allows the use of an air scour cycle as part of the backwash system, which is preferred for most applications. Refer to Reference 1 for an extended discussion of air scour systems and use. However, the pilot filter underdrain and support may

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Typical mixed media load surface area equals 4,400 ft^2 (based on the use of 16½ in. of Anthracite, 9 in. of sand, and 4½ in. of garnet sand)

NOTES:

1. Dual-media and multi-media designs use a layered approach to filtration where coarse solids are removed in the upper layer and the finer solids are removed at the bottom.
2. Multi-media uses a small particle size and a high surface area to improve the capture of small particles.

Figure 4-3 Typical media types

be best, on larger units, if they represent the equipment and material to be actually be used in the full-scale plant, even if additional height is required. Some owners may, in fact, prefer it.

Filter Media

The filter media used must be compatible with the underdrain and/or support gravel for both the pilot study and the full-scale plant. For example, not all porous plate underdrain systems are compatible with all granular media types. A brief description of some conventional media types is contained in Figure 4-3.

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Process Valves

The same valve arrangement should be used in the pilot as is intended for the full-sized plant. The valves can be manual or automatic. For temporary pilot filters, manual valves are most common, while automatic valves may be used for permanent units. The valves should include the same as will be used in the full-scale plant and typically include

- Influent on/off control
- Effluent on/off and rate control
- Backwash on/off supply
- Backwash rate control
- Backwash waste disposal
- Air scour supply

Flowmeters

Final effluent and backwash rate flowmeters should also be provided so that the actual rates used can be recorded. For temporary pilot units, pitot tube–type flowmeters may be used. For permanent units, flowmeters with an automatic transmitter may be desirable.

- **Pressure Gauges**—High quality pressure gauges and/or a differential pressure gauge for measurement of head loss are recommended.
- **Back Panel**—All equipment should be installed on a rigid back panel with the necessary piping and hose connections for influent, waste, effluent, and backwash purposes.

Greensand

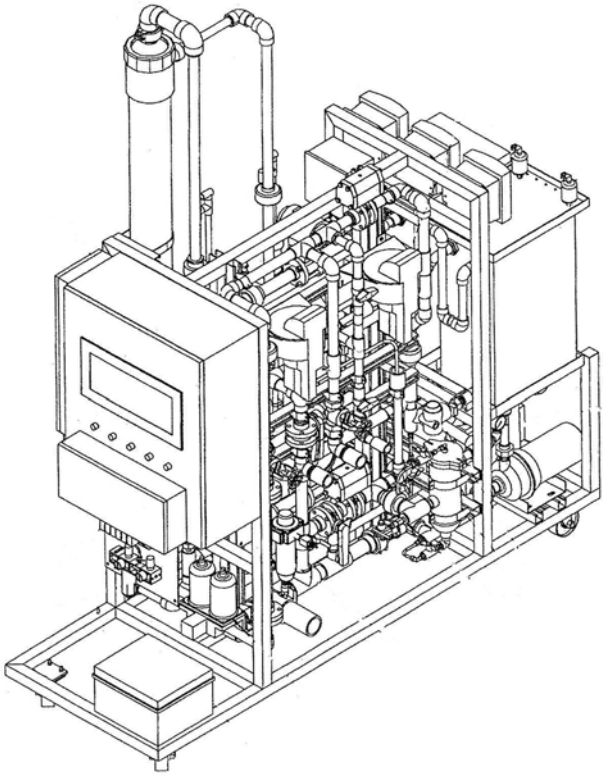
The same type of pilot filter can usually be used for greensand as well as for conventional media. There are several types of greensand, but the requirements for pilot testing are similar. It should be noted that a minimum depth of greensand of 30 in. is recommended, with an anthracite cap, if suitable sized material can be found. Any anthracite should be sized so that it will sit on top of the greensand without excessive intermixing.

Microfiltration

Skid-mounted microfiltration pilot units (Figure 4-4) are available and may include

- A minimum of one membrane module
- All the necessary pumps, valves, and controls
- A compressor to operate pneumatic valves (if used)

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Courtesy of Pall Corporation
Figure 4-4 Skid-mounted microfiltration pilot unit

- Clean-in-place (CIP) equipment and chemicals to maintain and clean the membrane module
- All required on-line instrumentation
- Computerized controls

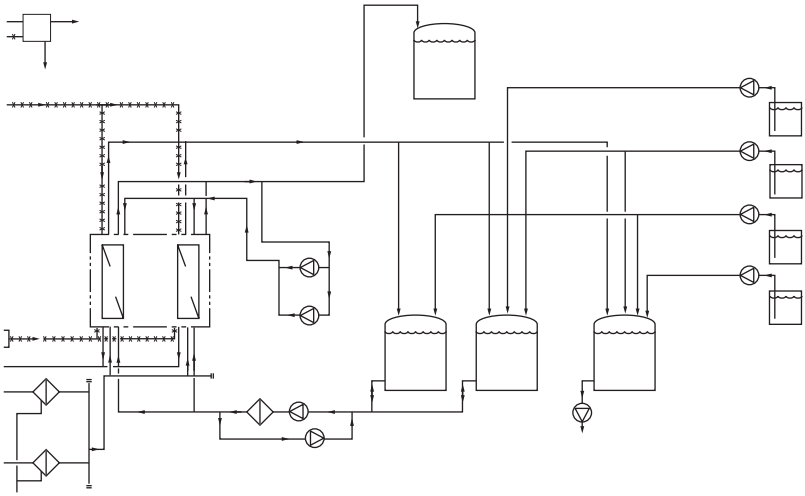
A flow diagram of microfiltration pilot equipment as supplied by the Pall Company is shown in Figure 4-5.

NOTE: The microfiltration pilot filter equipment previously described is provided with a complete operations manual, including installation instructions, and a troubleshooting guide.

Reverse Osmosis

The equipment for reverse osmosis is basically similar to that for microfiltration, except that higher pressures are used along with higher quality piping and valve materials.

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Courtesy of Pall Corporation

Figure 4-5 Flow diagram of the microfiltration pilot equipment

Slow Sand Filtration

Pilot filter units for slow sand filtration are not common and are typically built for the application, if they are required. As with all treatment types, the unit flow rate should be similar to that intended for the full-scale plant. Care should be taken to introduce the water into the filter in such a manner so as not to disturb the top of the sand.

PILOT FILTER EQUIPMENT SETUP

Many of the following recommendations may seem obvious, although there are installations that have not been set up properly.

- **Installation**—Make sure the equipment and chemical feed systems are plumbed correctly with materials compatible with the water to be tested.
- **Flocculation/Coagulation**—Flocculation/coagulation (if needed) will require detention time between the chemical injection point and the treatment unit. The amount of detention time will vary depending on the water temperature and the chemicals used. Some pilot units use a length of hose or piping for that purpose because it is easily modified.
- **Oxidation**—The oxidation of groundwater contaminants may only require minimal detention time and may be satisfied by the normal piping and fittings already used in the pilot unit.

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- **Chemical Feed**—Chemical feed systems for temporary pilot units often use 5-gal buckets or plastic trash cans for mixing and feed tanks.
- **Dilution of Chemicals**—Dilution for the chemicals must be calculated for the size of the pumps, the pilot equipment operating rate, and the anticipated feed rate (mg/L). It is important that the chemical mix dilution be made as accurately as possible, as it has a major impact on the results of the testing, as well as the selection and sizing of equipment for the full-scale plant. Typical calculations of the chemical pump rate is as follows:

$$\text{chemical pump rate (gpd)} = \frac{\text{mgd (pilot rate)} \times \text{mg/L (chemical feed)}}{1{,}000{,}000 \times \text{(chemical mix dilution)}}$$

- **Piping Connections**—A fresh (treated) water supply should be located and provided for backwash purposes. A discharge point for treated effluent and backwash waste should be located and provided as well. An untreated raw water source with the proper flow for the pilot unit(s) should be located and provided.
- **Instrumentation**—As noted previously, the pilot filter testing should not be performed unless the appropriate lab instruments are available to provide fast results for all the required data. Once good results are available, samples should be sent to a certified laboratory for formal confirmation.

PILOT FILTER OPERATION

The pilot unit(s) should be turned on. The raw water flow and chemical feed pumps should be turned on as well.

NOTE: The initial setting for the chemical feed pumps should be as determined in the bench-scale tests.

Take samples for testing after at least one volume of water has passed through the pilot unit.

Process Adjustments (Flow Rate and Chemical Feed Rates)

It is recommended that chemical changes not be made until after processing several bed volumes of water, which are adequate to produce consistent results. If the unit is not producing the desired water quality, it is recommended that chemical changes be made at that time. However, only one chemical should be changed at a time for testing purposes, to accurately determine its effect.

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NOTE: Generally, the water quality will not improve with longer runs without process changes, which may include chemical settings and/or changes in flow rate or flux rate.

Even if the initial water quality is good, testing should be continued until the optimum conditions are achieved and a confidence level is reached. If treated water quality is not good, the process flow rate or chemical feed rates should be adjusted (making only one change at a time) and testing should be tried again.

Record Keeping

Records of each run should be kept, either on paper or electronically, including chemical feed settings and unit flow rate. Keep a separate record of results any time any setting is changed.

Goals

The goal is to optimize both flow rate and chemical feed rates. High water quality, long filter runs, and the minimum chemical feed settings to achieve those conditions are the desired goals. These values will then be used in the design of the full-scale plant.

Formal Results

Once the on-site lab instruments indicate good results, representative samples of the treated water should be sent to a laboratory for formal confirmation. The laboratory results can then be included in the final report.

Consistency

When acceptable water quality is produced, the pilot equipment should be run as long as necessary for the operators to become familiar with the system and to determine if the filter run times are acceptable. As an example, if the water quality being produced is good but the filter runs are short, some process adjustments will be required followed by more testing to insure that optimum results have been reached. Also, each filter run should be similar in length to the others. If one is noticeably longer or shorter than the others, there is some problem that may have to be corrected and then reverified by more testing.

Example

The operation of a microfiltration pilot plant, which had never produced good quality water after two months of operation, was taken over by the author. The previous operators had attempted to operate

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the pilot plant on the same theoretical chemical feed rates the entire time without changing anything and without doing any bench-scale tests to determine the proper settings. The pilot testing failed because of the lack of a comprehensive testing protocol covering a range of flow conditions and chemical feed settings, and there were also errors in setting up the equipment.

The first step after taking over the pilot study operation was to conduct bench-scale/jar tests to establish the proper chemical feed rates, which took approximately two days once the tests were started. Meanwhile plumbing changes were made to the test unit. On the third day, the first day of operation, the pilot plant was producing high-quality water.

If the recommended complete testing procedure is followed, the pilot treatment should be successful in a very short time. Testing for verification can then be run as long as desired.

PILOT TESTING SUMMARY

The importance of bench-scale/jar testing is often overlooked due to the presence in many plants of streaming current monitors (SCM) and particle counters. However, bench-scale jar testing is highly important to identify the proper operating range of the plant quickly.

If problems occur while operating the full-scale plant, the pilot study report should be referred to in order to determine how those problems were resolved.

A permanent pilot filter unit is recommended for all larger treatment plants. These units have numerous uses including an early warning of treatability changes, operator training, and conducting chemical trials if testing new chemicals is desired. It is recommended that chemical trials not be conducted on the full-scale plant.

NOTE: Package treatment plants ordinarily do not have permanent pilot filters because of the short residence time in that type of equipment. The residence time is the length of time required for the water to pass completely through the plant. For a conventional plant, the residence time could be 2 hours or more, while a package plant may only require 20–30 minutes.

It is also recommended that the plant operators be involved in the pilot filter program to learn how the new full-scale equipment will operate. Training the plant operators in the use of a pilot filter is highly recommended so that they can conduct the tests and determine for themselves how the filter works. Hands-on training is always the best.

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CHAPTER FIVE

Process Design Notes

The following process design notes are provided so that the operator may have a better understanding of how the plant should be laid out and organized, prior to the actual design process. It is not necessary that the operators be designers or that they have design training. It is necessary that the operators have a good understanding of the process issues and equipment with which they will be working.

BASIC DESIGN PHILOSOPHY

The design of the full-scale plant should be based on the pilot study and/or similar plants on the same source water, including unit flow rates, chemical processes, and so on. Also, the plant controls should be designed to implement the processes that were piloted and should be simple to operate. In addition, it is recommended that the pilot study report be included in the plant operations manual as a reference for the operators.

The designer should provide a plan designed to meet the clients' specific needs. If a complex operational system is needed, the plan should reflect this and not just a generic operation.

The clients should be involved during the entire design process for several reasons. They will know if the project meets their needs; they will have a better idea of the operational requirements; and they will be able to have input on issues relating to maintenance.

The clients need to "buy in" to the design procedure and treatment processes. *Buy in* means that clients have been involved in every phase of the design process and both understand and are in agreement with all the issues.

Operation

The clients should provide input on how they would like/need to operate the system. Again, a complete description of the proposed plant operation and the anticipated operational requirements should be provided to the clients during the design process in sufficient detail to allow them to properly understand the issues.

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If the plant is remotely operated, it may need more operational alarms and automatic features. Some small plants may operate this way, but it is not recommended. Operators need to see what is happening. For example, there could be a chemical leak, which would need to be detected and repaired very quickly. If remote operation is necessary, a portable laptop computer is recommended for operators to carry when away from the plant, with full plant operational capability.

If the operators are on call or are part-time, the control issues will be similar to those discussed previously. Here again, part-time operators are not recommended when the public health is involved, unless the raw water quality is very stable and easy to treat. Funding for a full-time operator will be difficult for a small system. However, it should be noted that a small system has the same operating issues that a large plant has and the same health concerns.

When the operators are on-site full time, they can react to problems faster and more effectively. In this case, the controls can allow for more operator decision making, with less reliance on automatic controls, which is desirable in many cases, especially when the raw water quality is "flashy" and subject to rapid change.

Continuous operation is best, even if the plant has to be operated at a reduced flow rate. Frequent starts and stops are not normally good for treatability. Steady-state operation is best.

Frequent on/off operation can result in unstable flow in the plant, depending on the type of treatment equipment used. Variable rate operation can also result in inaccurate chemical feed changes, depending on the accuracy of the equipment. For example, flowmeters can be slightly out of calibration, and chemical feed equipment may not respond in a linear fashion, which can result in inaccurate chemical feed rates. In other words, a 10 percent increase in plant flow might only result in an 8 percent increase in chemicals, due to pluggage or fouling in the chemical pumps. For that reason, frequent cleaning and calibration of the chemical pumps are recommended. Therefore, an on/off type of operation is not recommended unless absolutely necessary. Even then, constant operator attendance is recommended.

A comprehensive discussion, or discussions, should be conducted with the plant owners, to insure that they understand completely what will be required for proper operation. Many issues are involved, and clients would do well to be prepared for the requirements for taking over and operating a new plant.

Maintenance Requirements

A periodic review of the plans during the design process can have a number of benefits for the owner/operators. For example, hose bibs

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can be located in multiple locations, as suggested by the operators, for cleaning and maintenance purposes. Adequate means for receiving and handling shipments of chemicals is another important issue. Adequate walkway space may need to be provided in equipment areas for clearance for a small forklift or pallet jack to move chemicals. Adequate space for access to equipment for maintenance purposes is another necessary item to be reviewed.

SUMMARY

The size and sophistication of the plant will obviously have a great impact on the design and the subsequent operation of the plant. It is, therefore, of great importance that someone with significant operational experience be in charge of the design, and that the clients are involved in the design process to increase their awareness of any operational or maintenance issues.

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CHAPTER SIX

Operational Design Issues

There are obviously a number of design issues that can affect the operation and maintenance of the plant. Some are discussed in the following sections.

RAW WATER SUPPLY

The design of the raw water supply system can impact the operation of the plant. In addition, these operational issues are different for surface water and well water supplies.

Surface Water

Depending on the design of the raw water supply system, the raw water introduced into the treatment plant may vary from that of the raw water source itself. There have been instances where the raw water intake pulled silt off the bottom of the impoundment, making the plant influent dirtier than it should be. The same condition can occur if the raw water has been stirred up considerably close to the intake. If the plant operators are having difficulties with the raw water quality, it may be necessary to have the raw water intake evaluated to determine if it is picking up excess silt or other forms of contamination. In some cases, design revisions have had to be implemented to improve handling of the source water.

Example. One surface intake was constructed on a river, where excess silt had built up against the intake well, causing pumps to fail and large amounts of silt to be sent to the plant, which overloaded the solids handling system. A silt dam had to be built up against the intake well to keep the silt out but still allow water in.

Every aspect of a plant design must be carefully considered to minimize both operational and maintenance problems.

Well Water Supplies

Wells have their own peculiar set of requirements: they have to be sited so that there is no influence by surface water; they have to be operated at a rate that will not draw the water level down too low; and they have to be tested periodically for contamination that might be

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drawn in from other sources. Some other issues are discussed in the following sections.

Example. One plant treated both well water and surface water after they had been mixed together. A decision was made to separate the treatment for the surface water and well water. When that occurred, unusual raw water quality from the well source was observed, which had previously been masked by the surface water treatment. The problem was traced back to the well. Many wells, with water containing iron and manganese, require disinfection several times a year for iron bacteria. Apparently, disinfection had never been practiced at this well.

Another problem at this same well was discovered regarding the use of oil lubrication in the well pump. Approximately 1 gal of food-grade oil per week was used for that purpose. Over time, the oil had passed through the pump and had accumulated down in the well casing and coagulated, creating a large volume of cottage-cheese type solids. Because of the iron bacteria and the oil, a considerable amount of solids was generated in the well casing and sent to the treatment plant. The well casing was completely fouled, and the well had to be rehabilitated.

During the rehabilitation, it was also discovered that the well's screen was not designed properly for the fine sand at that location. Many soil types have a wide range of particle size, so that during development of the well, the coarser particles are drawn in toward the screen to provide a filter for the smaller particles. However, in this case, there were no coarser particles. The well was rehabilitated, but it was not possible to change the screen, and the well was scheduled for complete replacement.

Comments

These examples are given to demonstrate that operational problems can occur that are often beyond the operators' control. In these cases, the operators will have to seek design assistance. However, it is important for operators to be able to identify the source of potential problems, even though they may not be able to resolve these issues by themselves.

CHEMICAL FEED SYSTEMS

As a general rule, flexibility should be designed into the treatment plant, to the extent possible. Examples of flexibility in chemical feed systems are discussed in the following sections.

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Duplex Chemical Feed Pumps

Duplex chemical feed systems are recommended. For example, a full size backup pump should be provided for every chemical system as a minimum. Then, the second pump will be available in case the first one fails or is off-line for maintenance. To keep them both in good operating condition and to even out the wear, the operation of the two pumps should be alternated frequently, daily or weekly for example.

Dilution Systems

Dilution systems should be provided for all viscous chemicals. Dilution water, added after the chemical pump, can result in more efficient delivery of the chemicals and reduced pumping pressure, in addition to better mixing at the point of injection.

Viscous/Hard-to-Mix Chemicals

Equipment for hard-to-mix chemicals is often highly automated and self-contained. Nonionic polymers are one such example. These polymers are provided as a powder and are highly viscous when mixed with water. The self-contained types of mixing equipment may produce very good results. However, open and accessible tanks are simpler and easier to maintain. For that reason, a mix tank/day tank system is preferred. Refer to Reference 2 for a description of chemical feed systems.

Multiple Chemical Feed Points

Multiple chemical feed points are recommended wherever possible. For example, it may be desirable to feed a polymer at the head of the plant as a coagulant aid. It may also be desired to feed the same or a different polymer in front of the filters. One treatment plant uses a cationic polymer as a coagulant aid and a separate nonionic polymer as a filter aid. Because of the peculiarities in the raw water at that site, that plant required the use of both polymers at the same time for effective treatment.

Chemical Response Time

The chemical pumps should be located as close as reasonably possible to the point of injection. The purpose is to reduce response time to changes in chemical rates. The longer the chemical delivery pipelines, the longer the response time.

The response time is the time it takes for changes in chemical feed dosages to actually reach the point of injection. If the chemical delivery pipeline is filled with 100 percent chemical (the same as in a chemical

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feed system with no dilution), changes in pump rate will be effective immediately. However, if dilution water is added to the pumped chemical, changes in the pump rate will affect the diluted chemical concentration, and the response time will be the time required for the new concentration to reach the point of injection.

NOTES:

- Whatever the response time, it must be included as part of the overall plant response time to any process changes. Process changes will not be complete until the new chemical feed rates have passed all the way through the plant. It is very important that additional chemical or flow rate changes not be made until the previous changes have had adequate time to pass entirely through the plant.
- Changes in flow rate only will affect the plant performance much more rapidly. However, in order to maintain the same parts per million chemical rates, the pumps will have to be changed in proportion to the flow rate changes.

Weather Protection

In the case of a large outdoor treatment plant, all chemical systems should be adequately protected from the elements, including direct sunlight temperature as well as normal weather conditions. A simple sun roof may be adequate in some cases, while complete enclosure and air conditioning may be required in others so as not to exceed the maximum temperature rating for the equipment or the chemical.

Example. One installation had a chemical feed system located outdoors in the direct sunlight. Summer conditions were such that the direct sunlight temperature was close to, or exceeded, the design capability of both the pump and the piping systems. Numerous failures occurred including rupture of the piping and failure of the chemical pump diaphragm.

In another case, a polymer system was inside a room that had a roof but the sidewalls were open to the atmosphere and there was no air conditioning. Ambient air temperature exceeded that of the rated storage temperature for the chemical. As a result, the chemical was ruined, and it coagulated into a solid form that fouled the delivery pipeline.

Methods of Injection

It is recommended that all chemical injection into a pipeline be done by way of an injection quill as shown in Figure 6-1. Chemicals injected in this manner will be much better distributed into the flow stream. In addition, the injection quill helps protect the pipeline material, which

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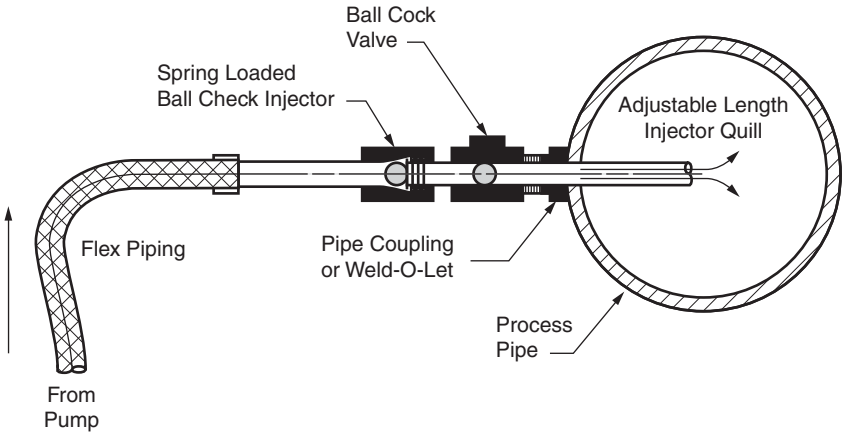


Figure 6-1 Injection assembly

is essential with metallic pipe. It may be obvious, but any wetted pipe or tubing materials should be compatible with the chemicals used. Other types of injection and chemical mixing are discussed in the following sections.

Examples. One site fed gaseous chlorine into the process piping through a brass fitting, which rapidly corroded and failed. Another plant injected a corrosive chemical into an ordinary grade of stainless steel piping and fittings, which also failed. In both cases, the use of an injection quill with plastic fittings would have resolved or greatly mitigated the problem.

Process Water Mixing

It is essential that chemicals be adequately mixed (rapid or flash mixing) into the process water stream as quickly as possible, especially when using coagulants or polymers. A total energy input of 3 ft of head loss is recommended for this purpose. For more specific recommendations, the chemical equipment manufacturers should be consulted for their recommendations.

NOTE: An important factor in the design of rapid or flash mixing is the anticipated variation in plant flow to be expected throughout the various seasons of operation. Mixing is accomplished in one of several ways.

Hydraulic jump or weir. Either a hydraulic jump or flow over a weir can be used for rapid or flash mixing. However, when using either, the effect on mixing of changes in flow rate should be carefully considered.

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If either is used, the designer should anticipate any potential problems that may be caused by entrained air resulting from the surface agitation.

Static mixers. Static mixers typically consist of a series of vanes inside the process pipeline. The intent of the vanes is to promote intermixing of the process water. However, the designer and operator should both be aware that the mixing intensity provided by static mixers varies with the process flow rate.

For example, if the necessary head loss is provided at the maximum design flow, the mixing intensity may be reduced by 75 percent if the process flow rate is reduced by 50 percent. Therefore, it is extremely important to determine in advance the anticipated flow rate conditions under which the plant is expected to operate, and to make sure that adequate mixing will be provided under all operating conditions.

In another example, package treatment plants may operate in an on/off mode at or close to the design rate most of the time. In that case, a static mixer might work well. However, larger plants may be operated at different flow rates, requiring different mixing. In either a package plant or a full-scale plant, the design must consider the anticipated plant operational modes.

Mechanical mixing. A mechanical mixer consists of a motor outside the pipeline that drives a shaft through water-tight bearings to a rotating propeller in the process stream. The amount of agitation is constant and is usually designed for the maximum flow. At reduced plant flow conditions, the actual mixing intensity is greater than designed.

Recommendation. Unless the plant is intended to operate at the same flow rate in an on/off condition, a mechanical mixer is recommended for a more flexible design, although a hydraulic jump may work as well if the plant design allows for the use of one.

Troubleshooting. If adequate rapid or flash mixing is not provided, the treatment efficiency between multiple filters may be different. At one treatment plant, one filter received more chemical than another because of the lack of adequate mixing at the point of injection. If treatment irregularities occur between filters or process trains, the adequacy of mixing after chemical feed addition should be investigated.

CHEMICAL DETENTION TIME

In many plants, the residence time (or detention time) of the chemically mixed water in the pipeline between the point of injection and the first stage of treatment can be critical. The necessary time can vary

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widely, depending on the source water, the type of treatment, and the water temperature.

Surface Water

With surface water, it is often necessary to coagulate the raw water with chemicals. The time required for that process to take place is dependent on the type of chemical used and the water temperature. The construction of the plant must allow for the necessary detention time, prior to the next treatment step. These issues should have already been evaluated and determined during the pilot study process. If there has been no pilot study, a very conservative design may be required.

Well Water

Typical contaminants in well water are iron, manganese, and arsenic. When removing these contaminants, an oxidation step is usually required. Chlorine and/or potassium permanganate are often used for this purpose. In that case, very little detention time is usually required for the oxidation process to occur. The normal piping system between the point of chemical injection and the filters is typically adequate for that purpose. However, this also should have been determined during the pilot study program.

Rapid or flash mixing of some sort may be necessary to thoroughly mix the chemicals in the water, to ensure the efficiency of the oxidation process if the detention time is short. Numerous pipe fittings between the point of injection and the filters may also be adequate for mixing purposes. Again, these issues must be carefully evaluated during the pilot study and the design process.

Note: Many operational design issues can be rectified after the initial construction is complete. However, the lack of adequate contact or detention time is difficult to change at that point. Therefore, this factor must receive considerable attention during the design process.

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CHAPTER SEVEN

Process Design

Process design includes a number of factors such as selection of the basic treatment process including the plant's water chemistry (should be done as part of the pilot study and preliminary design); selection of the operating components such as pumps and valves; selection of the underdrain, filter media, and/or membrane systems; and the selection of and location of the instrumentation. The last step is to develop the control system that operates the plant.

TREATMENT PROCESSES

The following discussions focus on designing the basic processes of a hypothetical water treatment plant. The intent is to determine the instrumentation, valves, and pumps to be used, and where the individual components are to be located. During this process, a flow diagram will be constructed, which is the first task in the design process. Preparing a flow diagram is also very important in establishing the operational procedures to be used in the plant. Understanding the flow diagram is also highly important for the operators.

For this discussion, it does not matter which type of plant is used.

- Direct filtration (chemical feed followed by filtration only)
- Package plant (a complete premanufactured treatment plant)
- Conventional (complete treatment including the following processes)
  - — Chemical feed (coagulation, filter aid, etc.)
  - — Sedimentation (clarification to remove heavy solids)
  - — Filtration (removal of fine solid particles with granular media)
  - — Disinfection
- Reverse osmosis (membrane filtration, usually for seawater, may need pretreatment)
- Ultrafiltration (membrane filtration)
- Microfiltration (membrane filtration)
- Special medias (greensand, etc.)
- Or any combinations of the above

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ASSUMED TREATMENT PROCESSES

This discussion will focus on a hypothetical conventional plant, including the components listed above for that type. The operational philosophy is more important than the plant type. Once that is understood, it is relatively easy to modify a flow diagram to fit other treatment types. The complexity of process design is in determining how to control valves, pumping systems, and multiple treatment trains while taking some of them off-line for backwash and then turning them back on, all the while maintaining the design flow rate. Valve speed even becomes important in maintaining proper control.

COMMON CHEMICALS

Selecting the chemicals needed should also be done in the pilot study/preliminary stage. The necessary pumps, tanks, piping, mixing equipment, and other related components are then selected to be compatible with the chemicals and are sized to meet the needs of the plant. Refer to Reference 2 for an extended discussion of these issues.

The following are some of the typical chemicals used in treatment plants. First listed are coagulants and filter aids:

- Alum—$Al_2(SO_4)^3 \cdot 14(H_2O)$
  - — Polyaluminum chloride—PAC
  - — Ferric chloride—$FeCl_3$
- Polymers (filter aid or primary coagulant)
  - — Cationic (liquid)
- Often used as a filter aid.
  - — Nonionic (powder)
- May be used as a filter aid or as a primary coagulant.
  - — Anionic (less common)

Common oxidizers (used as disinfectants and/or oxidation of dissolved metals) include the following:

- Potassium permanganate—$KMnO_4$
- Chlorine
  - — Gaseous—Cl
  - — Liquid—NaOCl
- Ozone—O_3

Common taste-and-odor control chemicals include:

- Powdered carbon (C)
- Potassium permanganate—$KMnO_4$
- Ozone—O_3

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Common buffering agents (used to raise pH and to add alkalinity) include:

- Lime
- Soda ash
- Sulfuric acid—H_2SO_4

Other common disinfectants include:

- Gaseous chlorine—Cl
- Liquid chlorine—NaOCl
- Ozone—O_3
- Ultraviolet light—UV
- Chlorine dioxide—ClO_2

NOTE: Each of the chemicals listed has specific design and operational needs. For example, the use of alum is pH dependent. In addition, many of these chemicals are corrosive and require special handling and piping materials.

PROCESS FLOW DIAGRAM

The water chemistry for a plant is tailored for each specific site, treatment type, and the contaminants that are present in the raw water. The instrumentation and controls are then designed to implement the water chemistry, all of which should be illustrated on a flow diagram. The completed diagram then becomes the basis of design and may include some of the equipment listed in the following sections.

Basic Processes

The basic treatment processes include raw water intake pumps, chemical feed pumps and mixing equipment, instrumentation, clarifiers, filters, process flow control, and so on. These items are discussed in more detail in the following sections.

Process Flow Control

Plant flow control starts with the raw water intake whether pumps are used or not. On/off or proportional control may be used, depending on how the plant is operated. Larger plants may use on/off control of multiple pumps and perhaps one variable speed pump for more accurate control.

Flow splitting is required when there are separate treatment trains. Separate flowmeters and flow control valves are usually required for each treatment train for flow splitting purposes. Weirs may also be used for flow splitting purposes.

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Accurate backwash flow control is necessary to insure adequate, proper cleaning of granular media (if used). The same is true for membrane systems. Flowmeters, flow control valves, and/or variable speed pumps may be used for this purpose

Accurate clearwell effluent flow must be monitored and recorded as a measure of product water sent to the distribution system. The clearwell effluent flow may be either by gravity or pumps. In either case, on/off or proportional flow control may be used. Modifying or controlling the effluent flow in any way requires that the raw water flow be adjusted accordingly.

Nearly every water system uses some type of chemical feed equipment. Water systems also need and use mixing after injection and either on/off or proportional flow control. Smaller systems tend to operate more in an on/off mode using manual speed controls, without any proportional or automatic variable speed control. Most other basic issues concerning chemical systems will be similar whether the system is large or small.

Raw Water Instrumentation

Raw water instrumentation is used for determining if adequate raw water is available for running the plant, for controlling the flow of water into the plant, and also for monitoring the water quality. Different types of commonly used instrumentation are discussed below.

- Well or surface impoundment level controls are used to insure that adequate raw water to run the plant is available. The level probes used for this function perform essentially the same service but may be of different types; one type having to go down a well casing, and the other usually having a wider surface to measure.
- Monitors for pH/temperature are typically for surface waters only because well water tends to stay at a relatively uniform temperature. The data from the instrument are used to monitor any changes in raw water quality and to assist in determining any process changes that need to be made.
- Turbidity monitors are also typically used for surface water only. The turbidity of well water does not usually change unless there is some sort of drastic failure. Turbidity monitors are also used to measure raw water quality and to assist in determining any process changes that need to be made. In worst-case conditions, the turbidity monitor may shut down the plant if the raw water becomes too dirty.

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- Particle counters are also typically used only for surface water. A comparison with the final effluent particle counts helps determine the efficiency of the treatment process.
- Silt density index (SDI) monitors are usually used for reverse osmosis applications to determine the effectiveness of the pretreatment processes.
- Conductivity is also used to determine the effectiveness of reverse osmosis.
- Alkalinity and/or hardness monitors are used for both surface water and saltwater applications to assist the operators in determining if any process changes are needed, especially in regard to coagulation.
- Flowmeters are used for all applications both to monitor the flow and to set the flow at the proper rate.
- Iron and manganese monitors (manual or automatic on line) are used primarily for well water to insure that water quality goals are being met.
- Silica monitoring is not common but may be used to verify the water quality for boiler feed (not common) applications.

NOTE: Automatic in-line monitors are recommended for all applications (if available).

Chemically Treated Water Instrumentation

Instruments for chemically treated water are located after chemicals have been added to the raw water and after mixing.

- A pH monitor is used in this location to verify that the coagulant dosage used is correct. It is especially necessary if a pH-sensitive coagulant, such as alum, is being used.
- Streaming current monitors (SCM) are also commonly used in this location. They monitor the particle charge in the water to insure that the water has been properly neutralized for coagulation.
- A chlorine residual analyzer may or may not be provided at this location, depending on the type of treatment being used. For example, if organics are present in the raw water, chlorine should not be added until after their removal in the clarification or sedimentation process.

NOTES: An SCM is not normally provided for well water supplies. A pH meter may not be required for all applications, but is recommended.

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Optional Clarification or Second-Stage Monitoring Instrumentation (Primarily for Surface Water)

- A turbidity monitor is often provided (and may be required) after clarification and before filtration to verify the efficiency of solids removal to that point.
- Particle counters may be provided at this location for the same purpose as a turbidity monitor, as previously discussed.

Filter Effluent Instrumentation

Instrumentation is necessary and required after treatment to verify that the water quality meets the regulatory standards before being sent to the distribution system.

- A turbidity monitor is the primary device used to prove that the water quality meets or exceeds the standards for treatment.
- Particle counters are also used to measure treatment efficiency and can be used, in some cases, to determine if one of the treatment trains is not as efficient as it should be.
- An SDI monitor (manual or automatic) is commonly used to verify that the pretreatment efficiency is adequate before reverse osmosis treatment. It is not commonly used in conventional treatment.
- Flowmeters are used to set the proper operating rate for each treatment train, as well as for the complete plant. They are also necessary for measuring the amount of water that has been sent to the distribution system. There are many types of meters available, and the best and most accurate should be used. Refer to Reference 1 for a more extended discussion of flowmeters.
- A head loss monitor/transmitter is recommended for each granular media filter (if used) to help determine when the filter needs to be backwashed. A head loss monitor can also be used to help troubleshoot filters and determine if they are operating properly.

Clearwell level probes may be used in the clearwell for several purposes including the following: monitoring and controlling the level to insure adequate volume for disinfection contact time (CT), insuring an adequate volume is available for backwash purposes, and controlling the final effluent pumps (if used).

A final pH adjustment monitor (if required) is used to verify that the final product water is produced at the proper pH level to reduce or prevent corrosion.

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Final Effluent Instrumentation

The final effluent instrumentation is located after the clearwell and after the final effluent pumps (if used) to verify that the product water was not contaminated after treatment or while in the clearwell.

- Turbidity monitors, pH monitors, SDI monitors, and particle counters have been discussed previously; however, they are also part of the final effluent instrumentation.
- A chlorine residual analyzer is required in this location to insure that the proper dosage of chlorine is added. Too much or too little will sound an alarm indicating to the operators that some change is necessary.
- A conductivity/hardness monitor is used typically for reverse osmosis treatment to verify that the pretreatment is run efficiently.
- Fluoride is often added to potable water. If so, it may be added in the clearwell after treatment. Installing an analyzer in the final effluent piping will allow the operators to verify that the proper dosage is used.

NOTES:

a. The above list of typical instrumentation is indicative of that which might be needed in a treatment plant and is not intended to be a complete list. In the preparation of a flow diagram, the instrumentation actually needed by the selected treatment process can be taken from this list, with others added as needed.
b. All data from the above instrumentation should be displayed on a computer screen for the operators' benefit.
c. Again, it is recommended that automatic in-line instrumentation be provided for all applications (if available).

SUMMARY

The intent of this chapter is to acquaint the operators with the various plant process components and how they are selected and located. The next chapter will locate those items in the flow diagram, which will then be the basis of design for the plant processes and equipment.

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CHAPTER EIGHT

Preparation of a Process Flow Diagram

In this chapter, a process flow diagram will be developed for a hypothetical treatment plant using the instrumentation and other equipment described in chapter 7. Even though the treatment processes may vary from one site to another, preparing a flow diagram with the associated instrumentation and equipment is similar for most plants and should be the first step in the design process. The intent is for the design process to implement the flow diagram. This information is provided for operators to assist them with understanding the processes and the function of the various types of instrumentation and monitoring devices. It is recommended that all operators be familiar with the flow diagram for their plant.

The equipment and instrumentation are added to develop the flow diagram in a series of stages, in order to illustrate the design process. It should be noted that the selection of instrumentation and equipment in the stages shown do not necessarily have to be done in that order. The order of the stages is selected in order of treatment for convenience only.

STAGE 1—THE BASIC PROCESS

For our purposes, the basic treatment process is assumed to be as shown in Figure 8-1. Although a conventional treatment system with flocculation and sedimentation is shown, the flow diagram is similar for pretreatment followed by microfiltration or reverse osmosis. In this figure, filtration is followed by a clearwell with final distribution pump(s) and also includes a backwash system.

Stage 1 of constructing the flow diagram includes the instrumentation and equipment used for controlling the raw water supply and the finished water discharge. Each of the basic components added in this step is discussed in the following sections.

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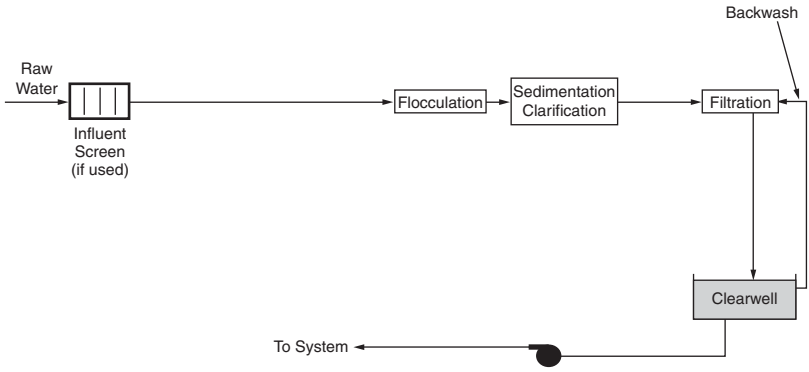


Figure 8-1 Process flow diagram, Stage 1: Basic process

Raw Water Supply

The raw water supply may be pumped from one or more wells, gravity flow from an impoundment, or one or more pumps from a surface source (either freshwater or seawater). In all cases, flow control and water quality monitoring are needed. When multiple pumps are used, whether from wells or a surface source, flow control becomes more complex as discussed in the following sections.

Flow and Pressure. When using multiple raw water pumps from either type of source, the pumps should have adequate pressure at full capacity as well as at reduced flow.

In the case of variable frequency (speed) drive (VFD) motors, the pumps have to produce the design pressure at the minimum flow, which means that excess pressure may be produced at high flow. Some process may be required to dissipate the excess pressure. Refer to Reference 2 for an extended discussion of VFD motors.

On/off control. If a pumping system is operating, care should be taken in turning the pumps on and off to mitigate pressure surges. Pressure surges can cause a number of different operational problems in the plant, including short-term water quality issues.

Finished Water Discharge

The finished water discharge includes clearwell design and capacity, level control, disinfection contact time (CT), and any required chemical feed and mixing.

Clearwell. The clearwell is intended, in many cases, to provide chlorine contact as well as to act as a pump well for the distribution pumps. There are several issues regarding the design of a clearwell

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including level control, chemical mixing (if post-filtration buffering is required), and the approach velocity to the pumps.

Level control and capacity. There can be considerable variations in the clearwell level, depending on changes in the plant operating flow rate, the operation of the filters, water required for backwash purposes, and the time required for the distribution pumps to turn off or come on line. For example, VFD pump motors (if used) may take 1 or 2 minutes to come up to full speed. The design of the clearwell is also an important factor. In some cases, the clearwell level is maintained at a constant level by a weir. Water then flows over the weir to the pump well where the water level could vary considerably depending on the operation of the pumps.

Therefore, it is common for pump wells to have a minimum 5-minute to 10-minute detention time (capacity), to account for these variations. In addition, the level and pump speed controls need to react very quickly. Refer also to Reference 2 and the pump manufacturers' recommendations.

Disinfection contact time. When the clearwell is used for chlorine disinfection, the contact time (CT) requirements will determine the minimum volume. Weirs may be used to maintain a minimum volume in the CT chamber, with the excess flowing over the weirs and into a pump well as previously noted. In that case, an additional 5 to 10 minutes of capacity may have to be allocated in the clearwell, for a separate pump well.

Chemical mixing. Chemicals may be added in the clearwell for disinfection (chlorine, etc.) and/or buffering purposes (alkalinity pH adjustment). When either is done, care must be taken to provide adequate mixing to disperse the chemical uniformly through the entire volume of the clearwell.

Example. At one treatment plant, lime was added to one corner of the clearwell. Because of the lack of adequate mixing, the pH measured in the clearwell effluent fluctuated widely, making the lime feed rate difficult to control.

Because of its high concentration, lime is fed as a slurry, with the intent of mixing and dissolving it in the flow stream before it can settle out. In this case, a large amount of lime settled out in the clearwell and created a mound over 6 ft high. The chemical settled out before it could dissolve, due to lack of adequate mixing.

NOTES: Chlorine disinfection is more effective at low pH. Therefore, maintaining a lower pH may result in a smaller clearwell. Refer to the standard USEPA CT tables for the required detention time.

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Pump Approach

In any type of raw or finished water pump well, it is necessary for the process flow to approach the pumps in a smooth and uniform manner and without turbulence. Severe operational problems can occur in the pumps if there are problems with the approaching water.

Example. At one installation, the pump capacity of an older wet well was increased 100 percent without consideration to the pump approach velocities, and it resulted in significant pump operational and maintenance problems. Doubling the process flow had the effect of doubling the velocity of the water and creating turbulence as it approached the pumps, causing cavitation and excessive wear. The pumps were having to be replaced or rehabilitated every 2 or 3 years as a result.

NOTES: For assistance in pump well design, refer to the pump manufacturer, pump design manuals, and/or information contained in Reference 2. These comments also apply to the design of raw water intakes.

STAGE 2—FLOW CONTROL

Flow controls are added to the flow diagram in three locations in this stage, as shown in Figure 8-2: on the raw water, on backwash supply, and on finished water. In each case, the equipment consists of a rate control valve and a flowmeter. The controls' software (programming) modulates the rate control valve in order to achieve the desired reading on the flowmeter, as set by the operator. Programming software is a separate issue and is not discussed in this handbook.

Raw Water Flow

The raw water flow rate is often used to flow pace the chemical feed systems (recommended). In other words, if the operator changes the plant raw water flow rate, the plant controls automatically change the chemical pump rates proportionally so that the same chemical rate is used at the new plant operating rate.

Backwash Flow

An accurate flowmeter is required to monitor the backwash flow. It is important for granular filter media and even membrane systems to be washed at the appropriate rate. Too high of a rate can result in the loss of media, while too low a rate can cause fouling of the media due to inadequate cleaning. It should be noted that the desired backwash flow rate is temperature dependent and should be adjusted accordingly. Refer also to Reference 1 for a more extended discussion of backwash rates.

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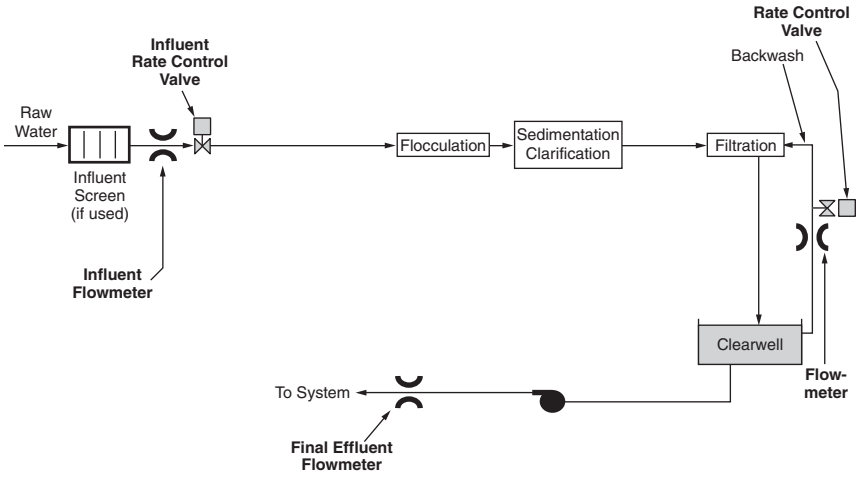


Figure 8-2 Process flow diagram, Stage 2: Flow control

Final Effluent Flow

The final effluent flow rate is the actual amount of treated water delivered to the distribution system. The final effluent flow rate may also be used to flow pace the final effluent chemical feed systems (if required).

Flow Control Valves

For flow control purposes with a low differential across the valve, electrically actuated butterfly valves are preferred that meet AWWA specifications.

Actuators. Electrical actuators are recommended for accuracy, for repeatability, for the available diagnostics, and for compatibility with computer controls. The gear drive on an electric actuator is much smoother than pneumatic or hydraulic units, which tend to be somewhat irregular and jerky in their movements. The manufacturer should be contacted if additional information is required on these issues.

Maximum differential pressure. Flow control valves modulate the flow by opening or closing as required to obtain the proper rate. The partially open valve then creates an amount of head loss as water passes through. The maximum differential head loss should be limited across a flow control valve of this type. Pressure gauges on both sides of the valve are recommended for monitoring the pressure loss.

The manufacturer should be contacted for differential pressure recommendations. As a general rule of thumb, the maximum differential pressure across a butterfly valve should be limited to 30 psi or less,

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preferably much less. A high differential pressure can cause cavitation with the associated vibration and valve wear. If greater differential pressures are required, a specialty valve of a different type may be required.

General flowmeter comments. Many different types of flowmeters are available from several different manufacturers, and it is necessary for operators and designers to know the operating characteristics of each. Operators and designers should visit other plants to see and hear what other operators like and dislike.

Entrained air and turbulence. Although some manufacturers claim that their flowmeters are not affected by entrained air and turbulence, entrained air should be eliminated to the extent possible, and flowmeters should not be installed close to pipe fittings, valves, or other piping components that can cause turbulence. Refer also to Reference 1 for an extended discussion of air removal.

Full piping. The pipeline and flowmeter should be full of water when either out of service or operating. Again, some flowmeters may be able to operate partially full, but it is better to not take chances if at all possible. Turbulence in partially full pipes may also be a problem.

Accuracy. An accurate flowmeter is desired to achieve proper operation of the plant. For example, if the flow measurements are not accurate, it may be difficult to obtain the proper chemical feed rates.

The flow inside a pipeline is seldom uniform across its width, especially when close to an elbow or other fitting. Normally, the highest velocity is expected to be in the center of the pipeline and lower velocity next to the side wall. However, the point of highest flow may actually be off center, with irregular velocities across the width of the pipeline. As a result, obtaining the best and most accurate flowmeter is recommended.

Recommendations. A summary of key flowmeter recommendations includes at least:

- Meters with no center bodies or obstructions in the flow path are recommended. Meters with these features may be difficult to keep clean and in proper operating condition.
- Magnetic flowmeters with multiple sensor/transmitters around the circumference of the meter body are preferred. Some of this type are able to operate with partially full pipelines and may also be able to tolerate some turbulence. Even so, eliminating entrained air and turbulence close to the meter is recommended for a conservative design and in order to help obtain the best data possible.

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